EXCITATION OF HYDROGEN ATOM IN FAST ENCOUNTER WITH NEGATIVE HYDROGEN ION

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ABSTRACT Born's approximation is used to calculate the cross-sections of the following processes :

$$H^-(1s^2)+H(1s) \rightarrow H^-(1s^2)+H(2s,\ 2p,\ 3s)$$

which are compared with the similar excitation processes

$$H^+ + H(1s) \rightarrow H^+ + H(2s,\ 2p,\ 3s)$$

and

$$H(1s)+H(1s) \rightarrow H(1s)+H(2s,\ 2p,\ 3s)$$

investigated by Bates, *et al* It is found that the cross section curves for excitation of hydrogen atom by hydrogen negative ion is characterised by two maxima, somewhat similar to those observed by Moiseiwitch and Stewart in excitation of helium by hydrogen. Results are presented mainly in graphical form

INTRODUCTION

The negative hydrogen ion in the photosphere of the sun has long been recognised as responsible for its continuous opacity in the visible spectrum. Recently Weinman and co-workers (Weinman-1955) have produced negative hydrogen ion by passing positive hydrogen ion from a magnetic ion source through a capillary tube containing hydrogen. Muschlitz-Bailey group at University of Florida (1955) have measured scattering cross section of low energy negative hydrogen ion in hydrogen and helium respectively using method of Simon and co-workers (Simon, 1943). In recent years detailed theoretical study of fast collision processes involving hydrogen and helium atoms and positive ions have been carried out by Bates and his group (1953) using Born's approximation. Considerable interest is attached to the study of the comparable processes involving H^-. The present paper is devoted to the investigation of collision of H^- and hydrogen atom, where the hydrogen atom is excited to various higher states from the initial ground state by the process. Born's approximation is used, no account is taken of exchange, though the range of validity of Born's approximation in present type of problem is still uncertain.

Problems of similar nature as

$$H^+ + H(1S) \rightarrow H^+ + H(2S,\ 2P,\ 3S)$$

$$H(1S) + H(1S) \rightarrow H(1S) + H(2S,\ 2P,\ 2S)$$

have been studied by Bates, *et al.*

THEORY

We consider collision of a hydrogen atom and a negative hydrogen ion, both particles being initially in their ground states. Ignoring the effect of the exchange identity of the protons and making use of the Born's approximation the cross-section of the process for which the hydrogen atom is excited to the state characterised by the quantum number nl, (the negative ion remaining at the ground state) is given by

$$Q(1S-nl,\ 1S^2) = \frac{8\pi^3 M^2}{K_i^2 h^4} \int_{K_{min}}^{K_{max}} |N|^2 K dK \qquad \dots \quad (1)$$

where 'h' is Planck's constant, 'M' is the reduced mass of the system and

$$\bar{K} = \bar{K_i} - K_f$$

$$\bar{K}_i = \frac{2M\pi \bar{V}_i}{h}\ ; \ K_f = \frac{2\pi M \bar{V}_f}{h}$$

$\bar{V}_i$ and $\bar{V}_f$ are the initial and the final velocities of the relative motion, and

$$N = \int e^{-iR.\bar{K_f}} \chi^*(nl,\ \rho)\phi^*(1s^2;\ r_1,\ r_2)$$

$$\times \left\{ \frac{e^2}{|\bar{R}|} - \frac{e^2}{|\bar{R}+\bar{\rho}|} - \frac{e^2}{|\bar{R}-\bar{r}_1|} - \frac{e^2}{|\bar{R}-\bar{r}_2|} + \frac{e^2}{|\bar{R}+\bar{\rho}-\bar{r}_1|} + \frac{e^2}{|\bar{R}+\rho-\bar{r}_2|} \right\}$$

$$\times e^{i\vec{R}\cdot\vec{K_f}} \chi(1S;\ \rho)\Phi(1S^2;\ r_1,\ r_2) d\bar{r}_1\, d\bar{r}_2 d\rho d\bar{R}$$

where $\bar{R}$ is the relative position vector of the nuclei of the two atoms, $\bar{\rho}$ the position vector of the electron of the hydrogen atom relative to the proton, χ's are the wave function of the hydrogen atom in the state indicated, and $\bar{r}_1$, $\bar{r}_2$ are the position vectors of the electrons in the negative hydrogen ion relative to the proton; Φ being the wave function of the hydrogen ion :

$$\phi = \frac{\alpha^3}{\pi a_0^3} \exp\left\{-\frac{\alpha}{a_0}(r_1+r_2)\right\}$$

with $\alpha = 0.688.$

It can be seen that in the integral for 'N' $\frac{1}{|\bar{R}|}$, $\frac{1}{|\bar{R}-\bar{r}_1|}$ and $\frac{1}{|\bar{R}-\bar{r}_2|}$ do not contribute due to the orthogonality of hydrogen atom wave functions. Therefore we got after integrating

$$N = \frac{-a_0{}^2 4\pi e^2}{t^2}\left[1-\frac{2.16.\alpha^4}{[(2\alpha)^2+t^2]^2}\right]\int \chi_{nl}{}^*(\rho)e^{-ik.\rho}\chi_{1s}(\rho)d\rho \qquad \ldots \quad (2)$$

where $$t = Ka_0.$$

From (1) and (2) we have

$$Q_{nl} = \frac{4c^2}{v_i{}^2}\left(\frac{2\pi e^2}{hc}\right)^2\int_{t_{min}}^{t_{max}}\left[1-\frac{2.16.\alpha^4}{[(2\alpha)^2+t^2]^2}\right]^2 I^2{}_{nl}t^{-3}.dt \qquad \ldots \quad (3)$$

where $$I_{nl} = \int\chi_{nl}{}^*(\rho)e^{-ik.\rho}\chi_{1s}(\rho)d\rho.$$

Now

$$t_{max} = a_0\, K_{max} = a_0(K_i+K_f)$$

$$t_{min} = a_0\, K_{min} = a_0(K_i-K_f)$$

As is usual in the treatment of heavy particle collisions, it is sufficient to take t_{max} as infinite (Bates *et. al.* 1953) and if ΔE is the difference in energy between the two states for a particular excitation processes then

$$t_{min} = a_0 K_{min} = \frac{a_0\Delta E}{\hbar v_i}\left[1+\frac{\Delta E}{2Mv_i{}^2}\right]$$

2.2. For discrete transitions I_{nl}'s can be calculated from (4) by elementary methods. They have been tabulated by Bates and Griffiing. We quote their value; :

$$I(1s-2s) = \frac{2^{17/2}\, t^2}{(4t^2+9)^3}$$

$$I(1s-2p) = \frac{2^{15/2}\cdot 3t}{(4t^2+9)^3}$$

$$I(1s-3s) = \frac{2^4\cdot 3^{7/2}\,(27t^2+16)t^2}{(9t^2+16)^4}$$

On substituting them in (3) one can obtain analytical expressions for cross-sections. But they are in general cumbersome and are very tedious to evaluate. It is much easier to evaluate the integrals numerically, which is actually done in this paper.

2.3. It can be seen from the expression (3) that if

$$\frac{2.16.\alpha^4}{[(2\alpha)^2+t_{min}{}^2]^2} << 1$$

then the expression for the cross-section becomes

$$Q(1s-nl) = \frac{4c^2}{v_i^2}\left(\frac{2\pi e^2}{hc}\right)^2 \int_{t_{min}}^{t_{max}} I(1s-nl)^2 \cdot t^{-3} \cdot dt$$

which is the same as that of the excitation of hydrogen atom by proton. Thus the screening of the negative hydrogen ion has no effect on scattering if the incident energy is below certain value. If we take as first approximation

$$t_{min} = \frac{a_0 \Delta E}{\hbar v_i}$$

it follows that for ($1s-2s$ and ($1s-2s$) transitions the hydrogen atom-hydrogen negative ion cross-section will differ from hydrogen atom-hydrogen positive ion (proton) cross-section provided incident energy is greater than 500 ev.

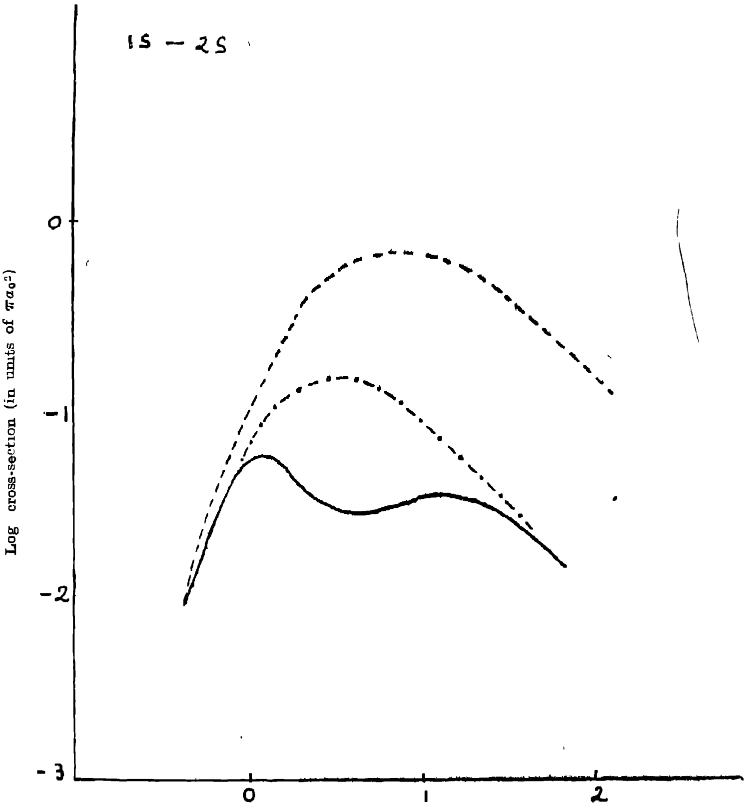
RESULTS

The cross-sections associated with the processes mentioned in the introduction are computed from the formula developed. Figures 1 to 3 show the values obtained. It should be noted that a log-log scale is used, and that the independent variable chosen is not E, the energy of relative motion, but the energy of the incident particle, the atom undergoing transition being taken to be at rest For comparison the cross-sections of proton-hydrogen atom and hydrogen-hydrogen atom as calculated by Bates and Griffiing are also plotted in the same figures.

On comparing the cross-section curve of ($H-H^-$) with corresponding curves for (p-H) and (H-H) respectively it will be observed that at low energy the cross-sections of (H-H^-) impact lie close to but above the cross-section of the latter processes. When energy is sufficiently low the (H-H^-) cross-section almost coincides with that of (p-H) impact. This is in conformity with the trend observed in (p-H) and (H-H) impact.

The curve for ($\mathrm{H}-\mathrm{H}^-$) is characterised by two maxima, somewhat similar to the double peaks observed by Moiseiwtsch and Stewart (1954) in collision between hydrogen and helium atoms. Moiseiwtsch attributed the phenomena to double transition. Essentially the same shape of curve has been obtained by Bates and Griffiing who however remark that if a better approximation method is used in the lower part of the energy region, the first maximum may be partially suppressed and the true curve may conceivably show a single broad maxima.

For ($1s-2s$) and ($1s-3s$) excitation the maximum cross-section is below that of the corresponding (H—H) crss-section and is shifted to considerable lower energy. But for ($1s-2p$) transition the maximum cross-section is in between that of (H—H) and (p—H) cross-section and is at higher energy.



Log Energy (in kev)

Fig. 1

...........$H^+ + H(1s) \rightarrow H^+ + H(2s)$

....$H(1s) + H(1s) \rightarrow H(1s) + H(2s)$ } Bates & Griffing

———— $H^-(1s^2) + H(1s) \rightarrow H^-(1s^2) + H(2s)$

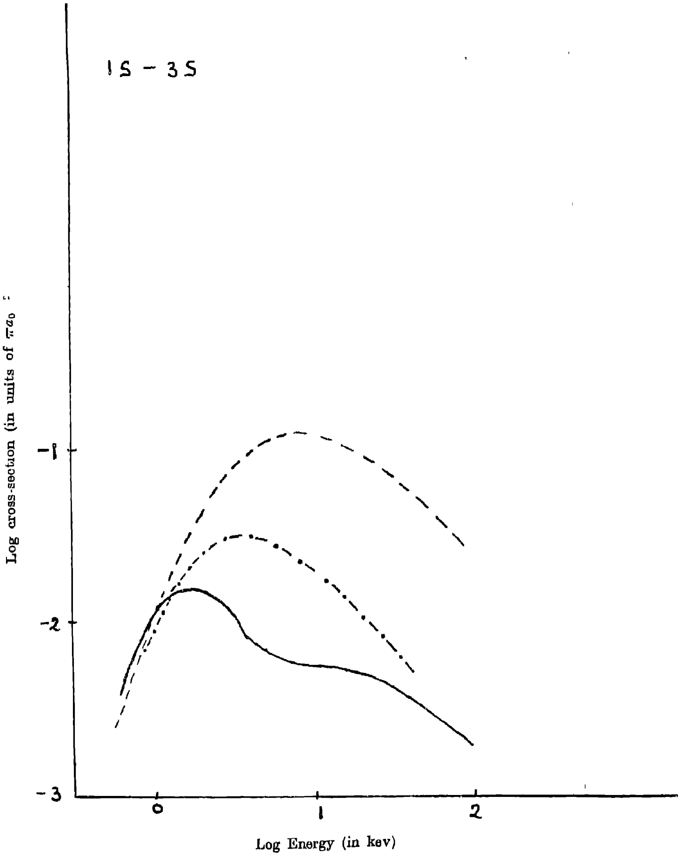


Fig. 2

............$H^+ + H(1s) \rightarrow H^+ + H(2p)$ } Bates & Griffing

—o—o—$H(1s) + H(1s) \rightarrow H(1s) + H(2p)$

————$H^-(1s^2) + H(1s) \rightarrow H^-(1s^2) + H(2p)$

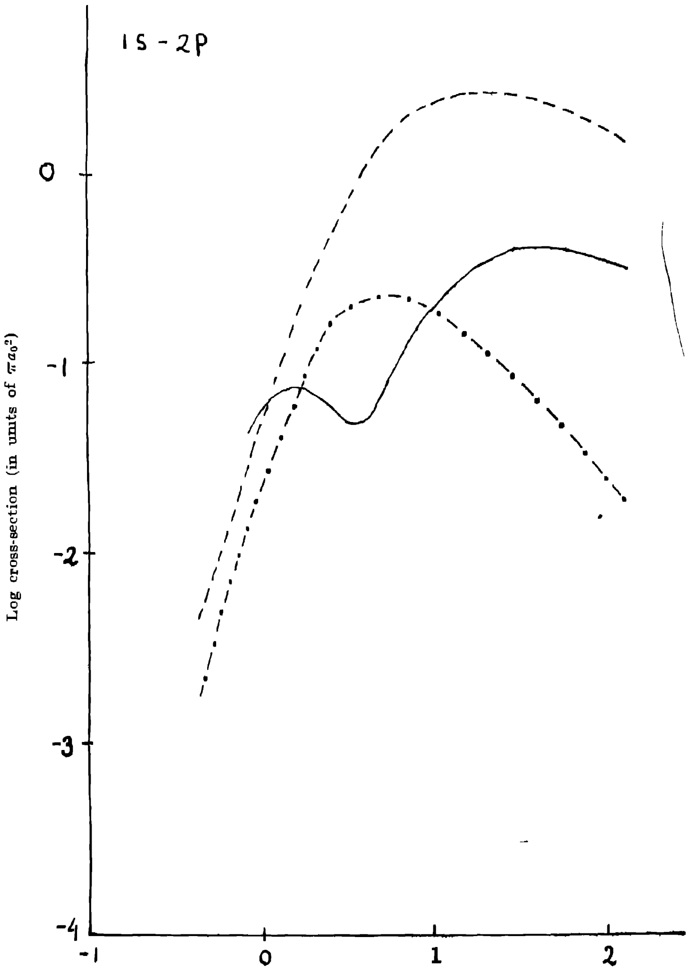


Fig. 3

............$H^+ + H(1s) \rightarrow H^+ + H(3s)$
—o—o—$H(1s) + H(1s) \rightarrow H(1s) + H(3s)$ } Bates & Griffing
— — — —$H^-(1s^2) + H(1s) \rightarrow H^-(1s^2) + H(3s)$

At higher energy the curve for $(1s-2s)$ and $(1s-3s)$ transitions almost coinsides with that of the (H--H) curves for the corresponding transitions, while the curve for $(1s-2p)$ transition lies above (H—H) curve and has a tendency to coincide (with (p-H) curve from below

Unfortunately no experiment is done in the energy region of this calculation. Only available data are due to E. E. Muschlitz who measured the scattering cross-section of H^- in hydrogen and helium in the energy range 4 ev. to 300 ev.

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